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31 August 1962

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MEMORANDUM TO: Chief, NPIC/TID

SUBJECT: Discussion of Proposal to be Submitted

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1. Meeting was held with representatives of [redacted]
New York on 27 August 1962. Those attending were:

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2. Meeting was concluded with the decision that [redacted] will
submit a proposal wherein they will offer to do the following:

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a. From the star exposures resulting from M-13 and subsequent KH-4 missions they will determine the relative and absolute pitch, roll, and yaw, until such time NPIC is prepared to do the job.

b. Concurrent with the reduction of the orientation parameters they intend to establish production procedures that can be adopted by NPIC. These procedures are to include star identification and star measurements followed by a subsequent proposal for instrumentation that will facilitate mass reduction of data from stellar exposures.

3. [redacted] also stated that they would submit a proposal that if approved would permit them to calibrate the black boxes (stellar and terrestrial camera combination) for all pertinent KH-4 mission.

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It is worthwhile noting that [redacted] is responsible for the calibration of the entire "A" system and that accurate techniques, personnel and facilities are at the communities disposal. At present camera calibration of the framing camera is being done by ACIC with some action

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GROUP 1
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downgrading and
declassification

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SUBJECT: Discussion of Proposal to be Submitted by [redacted]

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[redacted] It is suggested that ACIC, St. Louis, be contacted to see what their opinion might be. It is my personal opinion that [redacted] of ACIC would be happy to let [redacted] take on the entire responsibility. [redacted] may offer some resistance for obvious reasons.

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[redacted]
Chief, NPIC/TID/TAB

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NPIC/TID/TAB [redacted]

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WORK STATEMENT FOR
DATA REDUCTION SERVICES

[] will perform the following services: 25X1
upon specified input data.

PHASE 1

- a. The computation of the absolute orientation of the optical axis of a star camera with respect to a defined geocentric coordinate system.
- b. The transfer of this orientation data into pitch, roll and yaw of a ground frame camera which is rigidly connected to the star camera but having an orientation of its optical axis nominally offset by 90° from that of the star camera.

Input Requirements

The accomplishment of Phase 1 will require:

1. the provision of star images and associated fiducial marks taken by the star camera;
2. the instant of exposure correlated to Greenwich Time;
3. an ephemeris also correlated to Greenwich Time;
4. calibration data for the relative attitudes of the optical axes of the star and ground cameras.

Approach

The computational processes will be accomplished upon inputs of measurements made on the star images and associated

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fiducial marks. These measurements will be accomplished by instrumentation and by procedures described in Appendix A. The computational processes leading to tip, tilt, and yaw data of the ground camera with respect to the defined geocentric reference system will be accomplished upon the measurements of the star images in conjunction with orbit ephemeris and camera calibration data. The computational processes and reference definitions are described in Appendix B. The work performed under Phase 1 will require less than two weeks for a batch of approximately 400 star frames provided that measurements are limited to four fiducial marks and 5 to 9 star images per frame. This time quotation also supposes that the time correlation, the calibration data and the ephemeris are available no later than one week after start of the measurements.

PHASE 2

Calibration of stellar/terrain camera system. Determine the relative attitude of a rigid combination of stellar and ground frame cameras, the optical axes of which have attitudes which differ by approximately 90° with respect to each other.

Input Data

The calibration procedures require at least three sets of star images taken by the camera combinations.

Approach

The technical approach for the calibration procedures

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is described in Appendix C. The measuring and computational processes for each calibration will take approximately one week from receipt of the star images.

PHASE 3

Determination of panoramic camera attitude requirements. The absolute and relative orientations of panoramic cameras to be operated synchronously with the frame camera package shall be determined.

Input Data

This task will require photographic imagery taken by the star frame camera package and by the panoramic cameras.

Approach

Under the assumption that the absolute orientation of the ground frame camera has been determined by the processes described under Phase 1 and in Appendix A, the absolute orientation of panoramic cameras taken simultaneously with or in between frame camera shots can be determined by the procedures described in Appendix D.

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APPENDIX A**Measurement of Star Images**

The Stellar Coordinate Reader at 

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facility is the measuring machine to be used in scaling distances of stellar imagery with respect to fiducial marks on film negatives. It permits evaluation of formats of less than 5 x 3 inches. The measuring system consists of three basic components:

1. The measuring unit composed of film holders, drives, and viewing screen.
2. The electronic racks containing the necessary electronics for operation.
3. The recording unit containing an auxiliary data panel and an IBM 526 card punch.

The Stellar Coordinate Reader has a measuring precision of 1 micron and a measuring accuracy of 3 microns.

The design of this machine has eliminated much of the fatigue factor associated with conventional measuring units. Two of the functional designs contributing to ease of operation are the automatic X-Y drives by a 'joy stick' arrangement and the automatic lock-on system to point imagery by an electronic servo system.

Operational procedures for measuring are carried out swiftly and easily by one operator seated at the console of the measuring unit. At this position, the operator has full view of the measuring area projected at approximately 24X enlargement on a 30" x 30" screen; he also has access to all

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controls for full operation of the measuring system.

The film rolls are loaded from the rear of the measuring unit and are held to the film platen by a film clamp and vacuum system. Frames on the film rolls are moved into position by film drives controlled from the console panel. Auxiliary data for descriptive and computer uses for each frame are set by switches in the Aux Data panel of the recording unit.

A typical measuring program for one frame requires the measurement of four fiducials, a number of stellar points, and repeat measurements of the same fiducials for the purpose of providing an automatic computer check on the quality of the measurements. The data output is in card format with two distinct types of recorded measurements--fiducial measurements and stellar measurements. These measurements are distinguished from each other through auxiliary data that are programmed into the recording unit and automatically punched into the data cards ahead of the measurements.

Measurements are recorded by control switches on the console panel in a programmed sequence for input into digital computers. The switches are activated by the operator when the servo has automatically locked-on to the point that is to be measured. The "joy stick" is used to drive the stellar imagery into the field of sensitivity for automatic lock-on by the servo system. The servo system is designed to lock-on to

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black dots on a clear background; therefore, negative star images are required for proper operation.

It is estimated that the measuring process consisting of four fiducials - six image points - four fiducials will take ten minutes per frame including all auxiliary data settings, film changes, etc.

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APPENDIX B**Computation of Tip, Tilt, and Yaw**

The data required to determine platform orientation are: the film coordinates of the fiducial marks and of three identified and any additional number of non-identified stars, the time of exposure, the vehicle ephemeris, and sufficient data to determine the approximate field of view of the star camera in celestial coordinates of right ascension and declination.

In order to utilize the existing computer programs, the format of the ephemeris magnetic tape must be identical to that used in existing programs.

The sidereal orientation of the star-taking camera is obtained as follows:

a) By making use of the fiducial measurements, the measured coordinates are reduced to the camera calibration system and are further corrected to remove the effects of radial lens distortion and aberration.

b) A preliminary orientation is computed from the corrected film coordinates of three measured stars which have also been identified in a star catalogue such as the Boss Catalogue. The program then identifies and computes the

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apparent place of all measured stars for the instant of exposure, and computes a final camera orientation utilizing all the measured star images and their sidereal geocentric coordinates.

A matrix defining the relative orientation of ground camera axes with respect to the star camera system must be supplied to the program. Upon this information, the program will then furnish the sidereal geocentric direction cosines of the ground system.

Utilizing the time of exposure, these direction cosines are referred to the Greenwich system, and using the geographic coordinates and azimuth from the ephemeris, they are referred to the local vertical system. At this point, it is possible to compute the yaw, pitch and roll angles as defined in the following paragraph. It should be recognized that the accuracy obtainable is limited by the accuracy of the determination of the sub-satellite point. If the sub-satellite position is in error by one mile, the resulting angular error of the orientation will be on the order of one minute of arc.

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Coordinate System1) Sidereal geocentric: $\bar{I}_1, \bar{J}_1, \bar{K}_1$

Origin: the geometric center of the reference ellipsoid

 \bar{K}_1 is a unit vector at the origin, parallel to the axis of rotation of the earth, and directed toward the north pole. \bar{I}_1 is a unit vector perpendicular to \bar{K}_1 in the direction of the vernal equinox. \bar{J}_1 is a unit vector perpendicular to the plane of \bar{I}_1 and \bar{K}_1 so as to form a right handed system.2) Local Vertical: $\bar{I}_2, \bar{J}_2, \bar{K}_2$

Origin: The latitude and longitude of the sub-satellite point on the reference ellipsoid

 \bar{K}_2 is the unit normal to the reference ellipsoid at the sub-satellite point, directed toward the vehicle \bar{I}_2 a unit vector determined by normalizing the projection of the satellite velocity vector onto the plane tangent to the reference ellipsoid sub-satellite point. \bar{J}_2 is determined as in 1).

This local vertical system may be obtained from 1) by performing the following rotations in succession:

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a) about k through the angle $\alpha = \text{GST} + \lambda$. (α = the right ascension of the vehicle at the instant of exposure). This rotation results in a set of new \bar{I}_1, \bar{J}_1 vectors.

b) about the new \bar{J}_1 axis through $(\frac{\pi}{2} - \varphi)$, where $(\frac{\pi}{2} - \varphi)$ is the geographic co-latitude of the sub-satellite point). This rotation results in a set of new \bar{J}_1, \bar{K}_1 vectors.

c) about the new \bar{K}_1 axis through the angle $(\pi - A)$.
 A is the azimuth from north and is measure clockwise as positive.
 A is given in the vehicle ephemeris.

3) Platform System: $\bar{I}_3, \bar{J}_3, \bar{K}_3$

This is the system the orientation of which is desired. It is completely defined by specifying a relative orientation matrix relating it to the star taking camera. For the purpose of this analysis, the coordinate system will be assumed to be a right handed system fixed with respect to the platform.

The platform system may be obtained from the local vertical system by successive rotations about:

- 1) the \bar{K}_3 axis through the angle ψ (yaw)
- 2) the new \bar{J} axis through the angle θ (pitch)
- 3) the new \bar{I} axis through the angle Ω (roll).

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Transformation Matrices

1) The matrix of direction cosines of the Sidereal system with respect to the local vertical system is

$$V = \begin{matrix} & \begin{matrix} -\sin a \sin A - \cos a \sin \phi \cos A & \cos a \sin A - \sin a \sin \phi \cos A & \cos \phi \cos A \end{matrix} \\ \begin{matrix} \sin a \cos A - \cos a \sin \phi \sin A \\ \cos a \cos \phi \end{matrix} & \begin{matrix} -\cos a \cos A - \sin a \sin \phi \sin A \\ \sin a \cos \phi \end{matrix} & \begin{matrix} \cos \phi \sin A \\ \sin \phi \end{matrix} \end{matrix}$$

2) The matrix of direction cosines of the vehicle system with respect to the local vertical system is

$$H = (h_{ij}) = \begin{matrix} & \begin{matrix} \cos \psi \cos \theta & -\sin \psi \cos \alpha + \cos \psi \sin \theta \sin \alpha & \sin \psi \sin \alpha + \cos \psi \sin \theta \cos \alpha \end{matrix} \\ \begin{matrix} \sin \psi \cos \theta \\ \sin \end{matrix} & \begin{matrix} \cos \psi \cos \alpha + \sin \psi \sin \theta \sin \alpha \\ \cos \theta \sin \alpha \end{matrix} & \begin{matrix} -\cos \psi \sin \alpha + \sin \psi \sin \theta \cos \alpha \\ \cos \theta \cos \alpha \end{matrix} \end{matrix}$$

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Letting S be the matrix of direction cosines of the vehicle axes in the sidereal system we have

$$H = V S = (h_{ij})$$

and the roll, pitch and yaw angles may be computed as follows:

$$= \sin^{-1} (h_{31})$$

$$= \tan^{-1} \left(\frac{h_{31}}{h_{11}} \right)$$

$$= \tan^{-1} \left(\frac{h_{32}}{h_{33}} \right)$$

ϕ will be determined by its principle value, and the quadrants of θ and ψ will be determined by quadrant analysis.

As a check on the computation, the H matrix may be re-computed from the literal values of its entries and compared element for element against the h_{ij} given above.


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**APPENDIX C****Calibration of a Stellar/Terrain Camera System**

The stellar/terrain camera system consists of two cameras rigidly connected and set at right angles to each other so that, while in orbit, the terrain camera is directed vertically downward towards the Earth and the stellar camera is directed towards the pole of the orbit. Knowing the attitude of the stellar camera as determined from star photographs and knowing the relative orientation of the terrain camera with respect to the stellar camera, the attitude of the terrain camera may be determined. It is essential, then, that the relative orientation of the terrain camera with respect to the stellar camera be precisely determined. In addition, to insure geometric fidelity in any measurements made on the photography, the complete inner orientation (i.e., principal distance, principal point, and radial lens distortion) of both the terrain camera and the stellar camera must be known. The inner orientations of the two cameras and the relative orientation between them are determined by camera calibration.

The computational procedures and data reduction programs, directly applicable for the calibration of the above camera system, have been used by  for some time. The calibration, carried out before flight, is based on photographing stars with the cameras to be calibrated. For the

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calibration of interior orientation, each of the two cameras, in succession, is directed towards the zenith and exposures are made of the stars. The star images are identified and measured and their coordinates are corrected for all systematic errors such as film shrinkage and atmospheric refraction. The true positions (right ascension and declination) of the identified stars at the instant of exposure are computed from the "Boss" catalogue. A least-squares adjustment of the measured star coordinates to their true positions, employing the condition of collinearity, will result in the determination of the inner orientation parameters of each of the two cameras. The calibration of the relative orientation between the two cameras proceeds in a similar manner. The two cameras, rigidly fixed together, are directed upward such that the minimum zenith distance is subtended by the system. Exposures of the stars are then made simultaneously with the two cameras. As before, the star images are identified, measured, corrected for systematic errors, and their true positions determined from the "Boss" catalogue. In the adjustment procedure, employing the same programs as those for inner orientation, the inner orientations are held fixed and the exterior orientation of each camera is solved for. The relative orientation between the two cameras is then found by taking the difference between the exterior orientations of each camera.

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APPENDIX D**Determination of Panoramic Attitude**


The complete camera system consists of a twin convergent panoramic camera system (the principal camera system) and a stellar/terrain camera system operating together in an orbiting vehicle. The space positions of each camera system can be determined for any given time (e.g., when exposures are made) by relating that time to the precise orbital data as obtained from the ephemeris. In turn, the attitude of the stellar-terrain camera system, at the instant any terrain exposure is made, can be determined from the simultaneously exposed stellar photograph. The remaining problem, that of determining the attitude (i.e., roll, pitch, and yaw) of the panoramic camera system, is solved by computing the relative orientation between the panoramic camera system and the stellar-terrain camera system.

The computational procedures and data reduction programs for performing a least-squares stereo-photogrammetric triangulation adjustment suitable for the computation of the relative orientation described above have been used by Autometric for the evaluation of space photography. Employing these procedures, it is necessary to identify and measure conjugate image points in the overlap area of the photographs;

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in this case, the terrain camera photograph and a panoramic photograph of the same area. The known positions of the two camera systems, the attitude of the stellar/terrain camera system, and the coordinates of conjugate image points (corrected for lens distortion, film shrinkage, atmospheric refraction, etc.) are then utilized in the least-squares adjustment. As a result of the adjustment, the attitude of the panoramic camera is determined. By employing a series of these adjustments with the additional available photography from both panoramic cameras and the terrain camera, the relative orientation between the two panoramic cameras and any changes thereof, as well as the absolute orientation of the panoramic package, may be determined from the previously determined orientation of the frame camera.

If area match techniques are employed for identifying and measuring conjugate images, a single conjugate point is sufficient for determining the attitude of each panoramic camera. Ideally, this point would be the principal point of the panoramic camera as defined by the intersection of the optical axis and the film plane at zero sweep angle. The panoramic camera principal point would be transferred to the terrain photograph by area matching and then its coordinates would be measured on the terrain photograph (the coordinates of the principal point on the panoramic photograph are $x = 0$ and $y = 0$). Since only one conjugate image point is measured,

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the adjustment program will require, in addition to the space positions of the two cameras and the attitude of the terrain camera, the orientation of the panoramic photograph match with respect to the terrain photograph coordinate system and the approximate terrain elevation of the conjugate image point. If, on the other hand, the terrain and panoramic photographs are simultaneously exposed (i.e., at zero sweep angle) they may be considered as having the same space positions and an approximate elevation of the conjugate image point will not be required. Finally, if only the relative orientations between the various cameras is required, the space positions of the cameras need not be considered as long as they are coincident.

Although only a small area around each panoramic camera's principal point is involved in the match, the determination of the yaw, pitch and roll of the twin panoramic camera system is quite strong since the base of the triangle formed by the ground positions of the two principal points and the exposure station is sufficiently long to allow accurate directional comparisons with the orbital ground track. Using only a single panoramic camera, the solution for yaw can be strengthened considerably, with respect to a single match around the principal point, by making a number of matches along the panoramic photograph x-axis (i.e. the axis perpendicular to the sweep direction at zero sweep angle). In addition, if the sweep and IMC corrections are known, points off the x-axis can be

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utilized to strengthen the solution still further. The present computational procedures and data reduction programs have the capability of handling any number of conjugate image points in the least-squares adjustment.

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A-414	SPECIAL HANDLING	Proposed Data Reduction Services for Certain Calibrations, Adjustments and Attitude Determinations. dated October 1962. Copies 1 through 24 incl.

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A 426	SPECIAL HANDLING	PROPOSAL TITLED "WORK STATEMENT FOR DATA REDUCTION SERVICES" - 18 PGS. Pg #'s 1, 2, 3, of 4

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